T-SDHCAL based on MRPC

Subtask 1.3.1

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IP2I Lyon CIEMAT

DRD6 Collaboration Meeting at CERN. April 2024

Institutes involved

- IP2I Lyon
- OMEGA
- CIEMAT
- UCO - University of Cordoba
- VUB - Vrije Universiteit Brussel
- GWNU - Gangneung-Wonju National University
- YCC - Yonsei Cancer Center GWNU
- SJTU - Shanghai Jiao Tong University
- University of Tunis El Manar

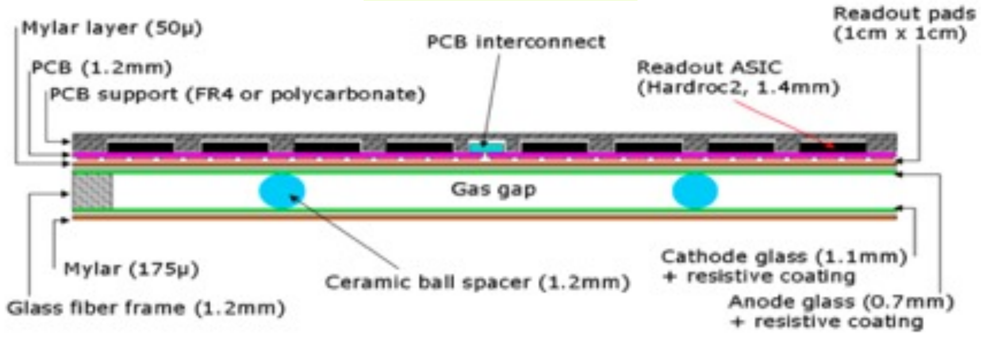
CALICE SDHCAL
Since 2012

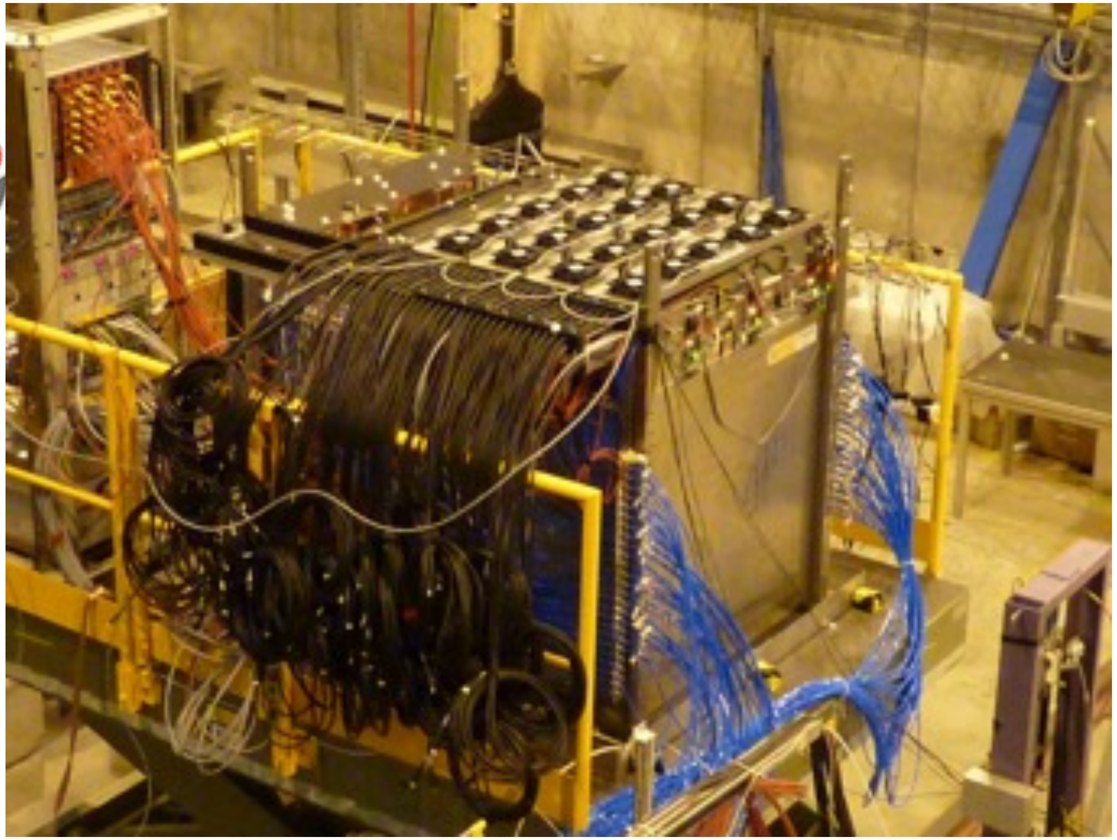
SDHCAL - Semi-Digital Hadronic CALorimeter

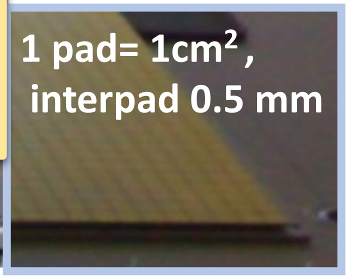
Sampling calorimeter:

Absorber: Stainless Steel + Detector: Glass Resistive plate Chambers

GRPC Sketch







- 48 layers ($\sim 6\lambda_I$)
- 1 cm x 1 cm granularity
  3-threshold, 500000 channels
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure

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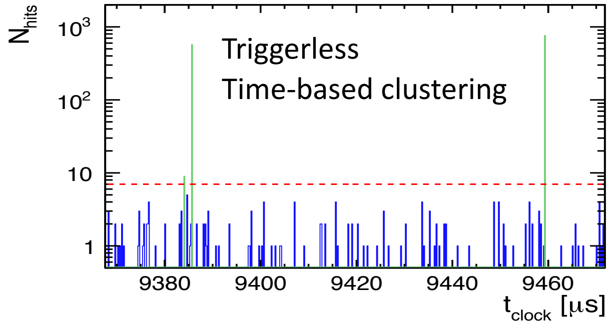
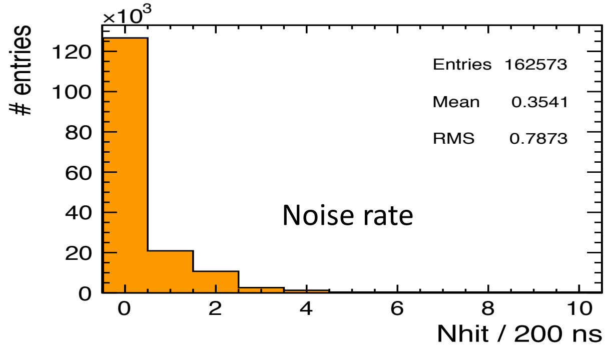
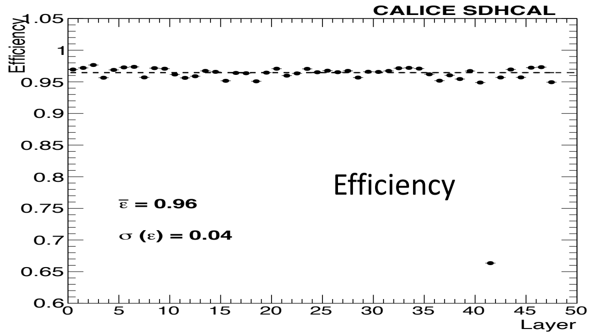
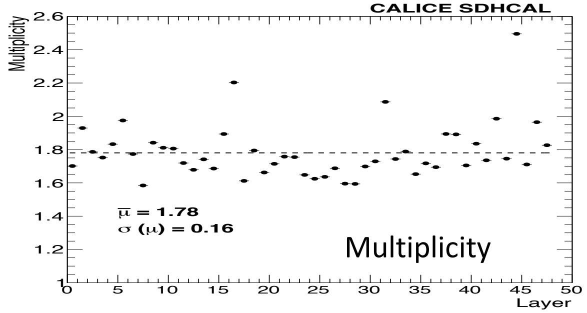
SDHCAL performance

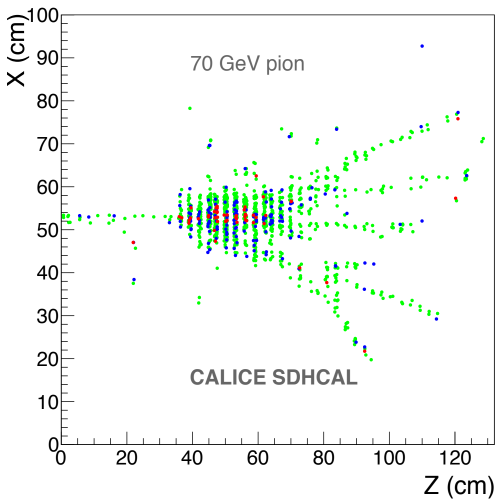
- The SDHCAL prototype was exposed to hadron, muon and electron beams in 2012, 2015 , 2018 and 2022 on PS, H6 and H8 -SPS lines.
- **Power-pulsing** using the SPS spill structure was used to reduce the power consumption.
- **Self-triggering** mode is used but external trigger mode is possible
- The threshold information helps to improve on the energy rec. by better accounting for the number of tracks crossing one pad
- Data were taken in 2012, 2015, 2017, 2018 and 2022 with continuously improved DAQ system.

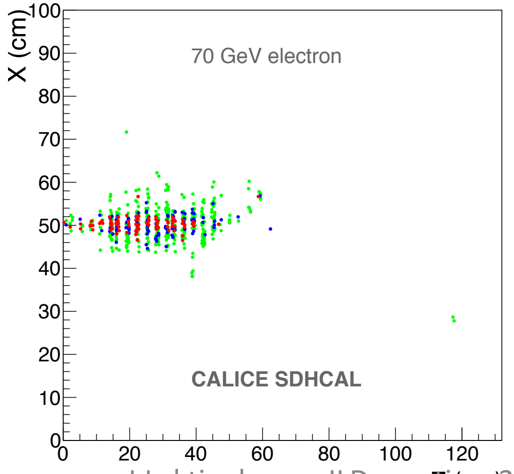












SDHCAL performance

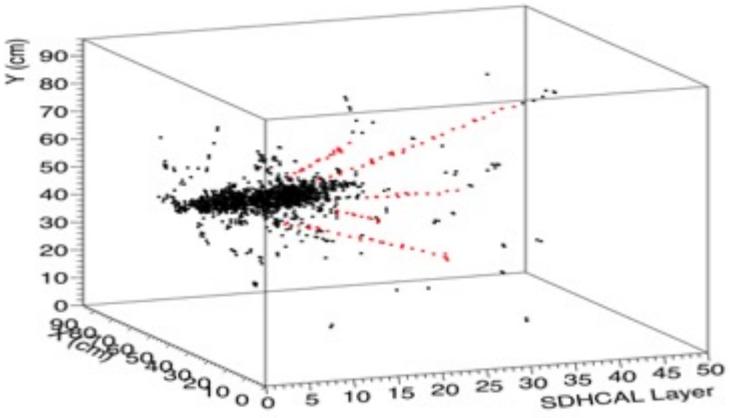
$$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$$

α , β , γ are **quadratic functions** of
They are computed by minimizing :

$$\chi^2 = (E_{beam} - E_{rec})^2 / E_{beam}$$

Hough-Transform

Track segments reconstruction using 3D-Hough Transform helps apply different treatment to the hits of these segments.



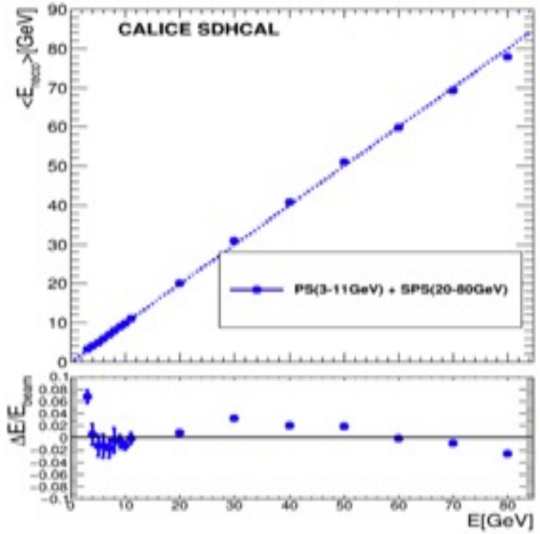
Track segments can also be used as in-situ calibration and monitoring tools

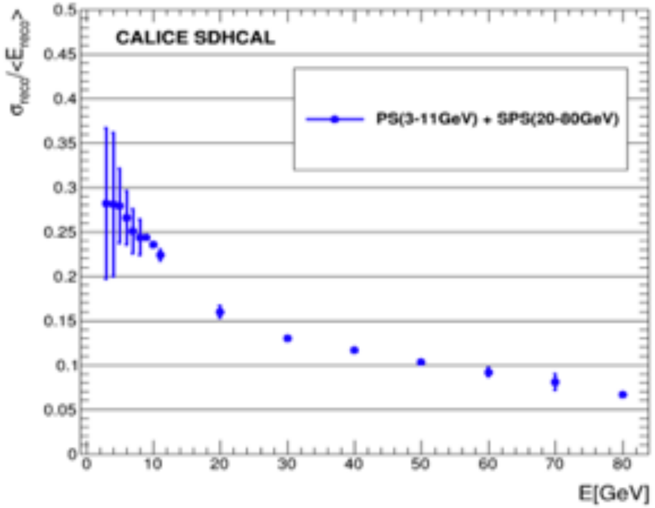
JINST 12 (2017) P05009

Energy reconstruction

JINST 11 (2016) P04001

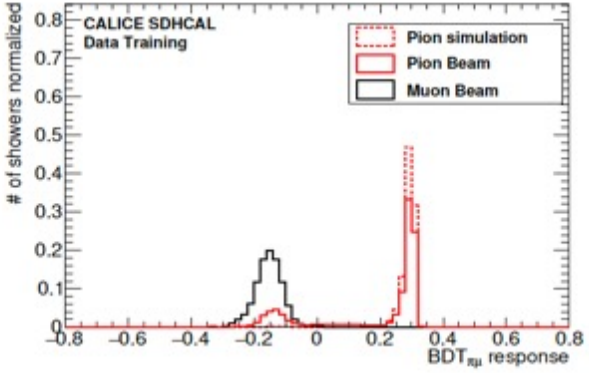
JINST **17** (2022) P07017

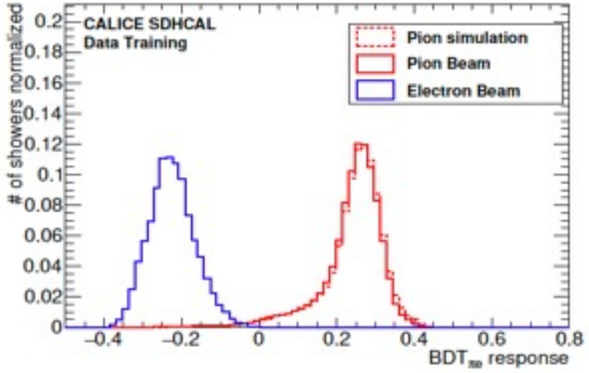




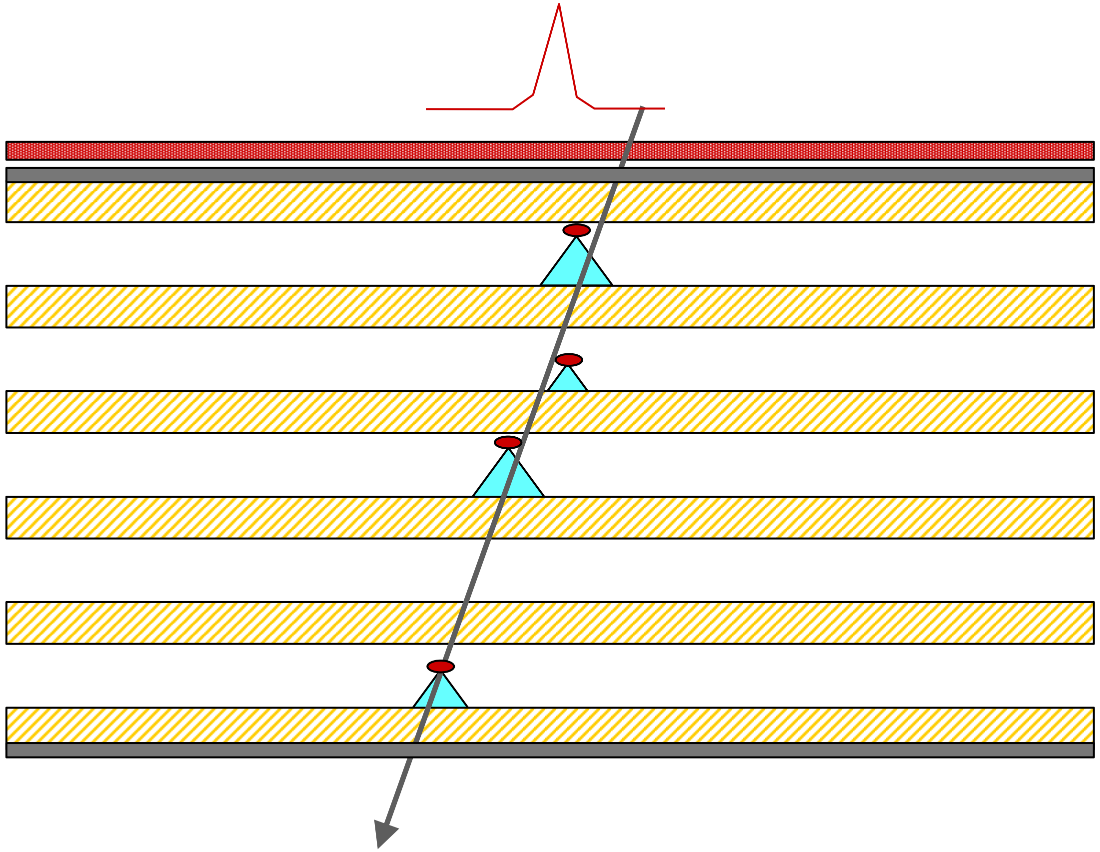
Particle identification

JINST 15 (2020) P10009



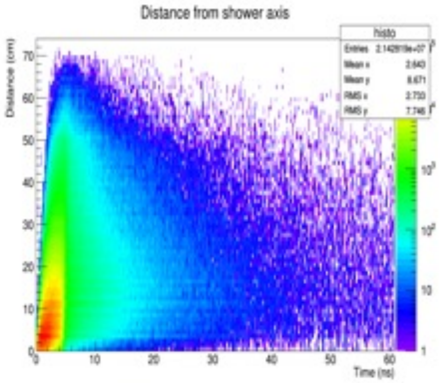


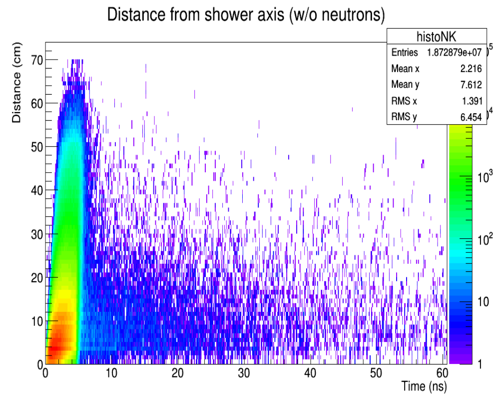
T-SDHCAL



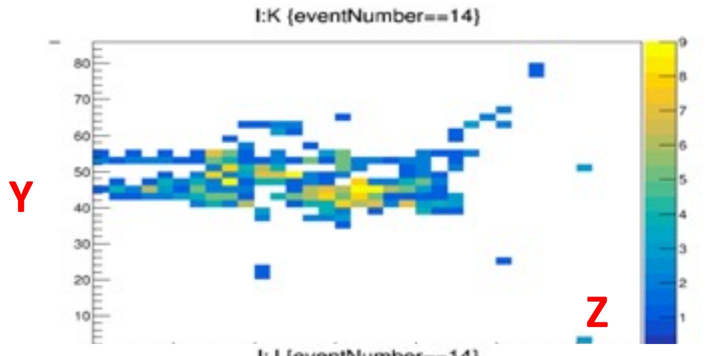
Why timing?

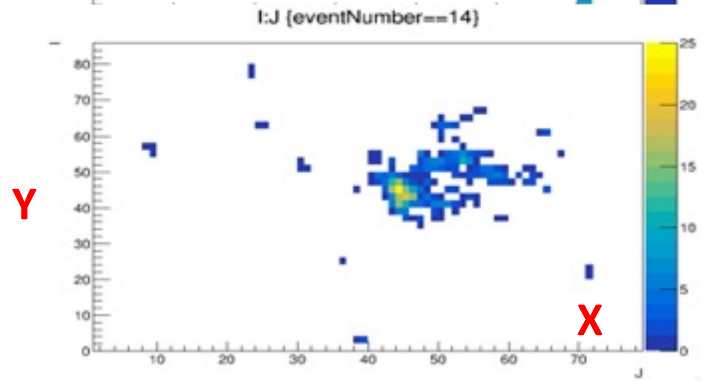
Timing is an important factor to identify delayed neutrons and **better reconstruct their energy**

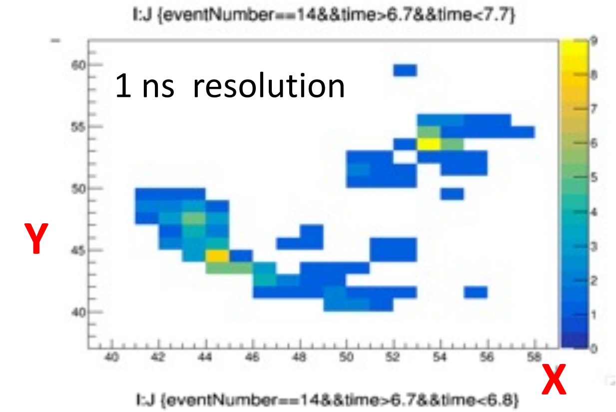


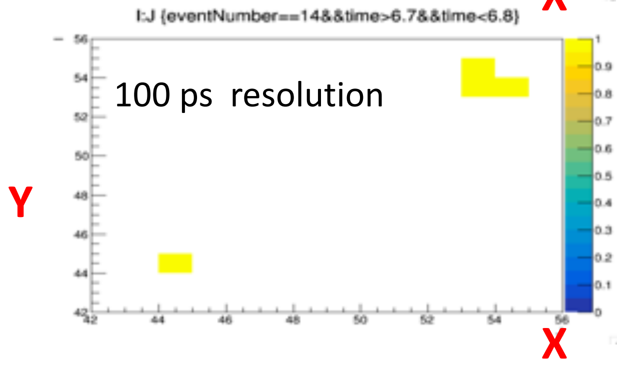


Timing can help to separate close-by showers and reduce the confusion for a better **PFA** application.
Example: pi-(20 GeV), K-(10 GeV) separated by 15 cm.



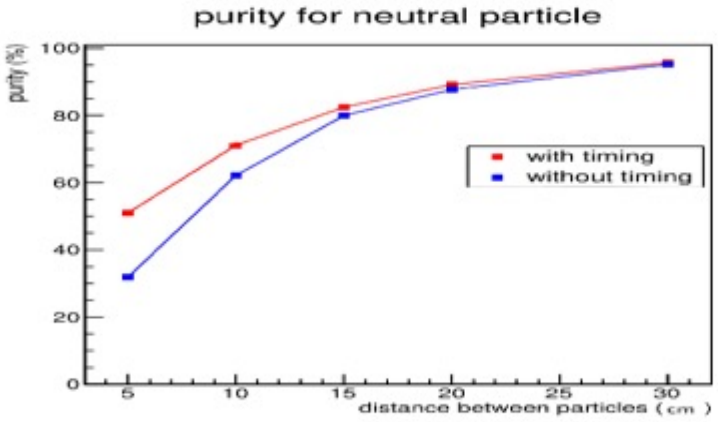


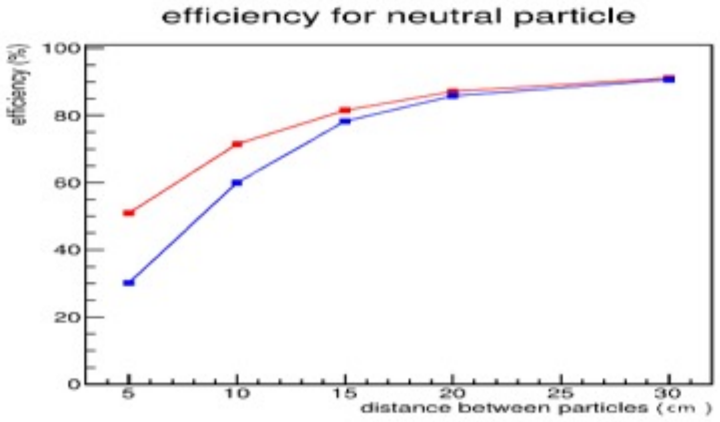


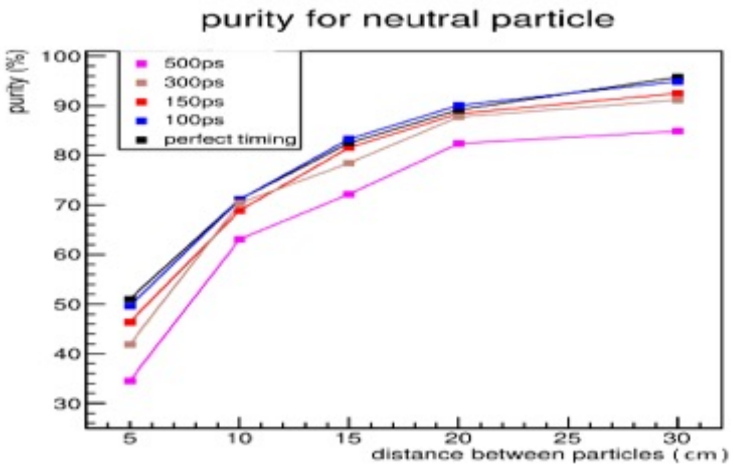


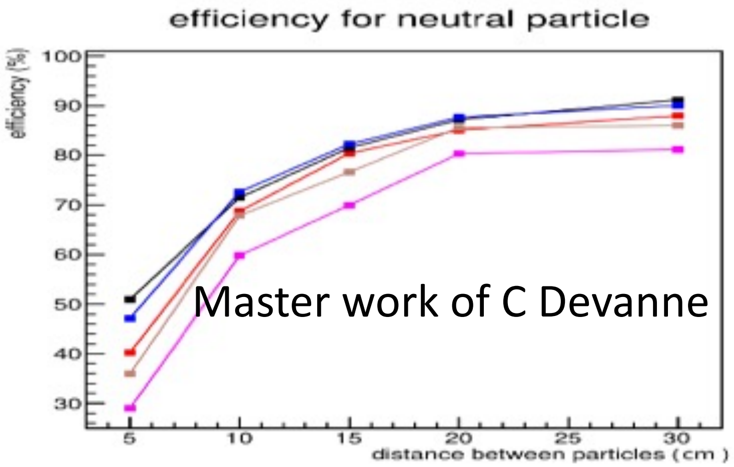
Improvements on shower separation when including timing

Including time information in the simulation to separate hadronic showers (10 GeV neutral particle from 30 GeV charged particle) using techniques similar to ARBOR's ones.







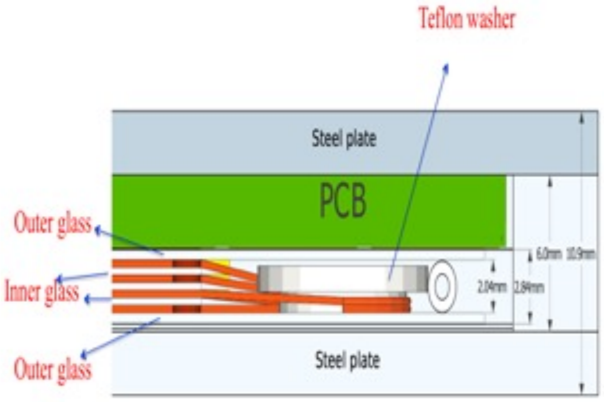


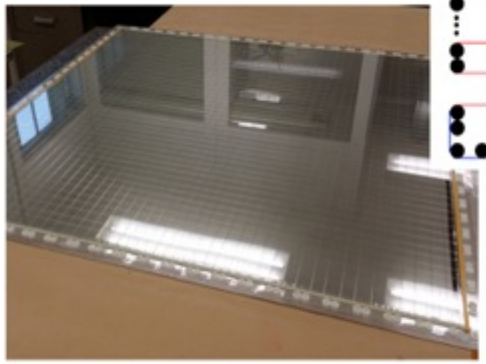
Master work of C Devanne

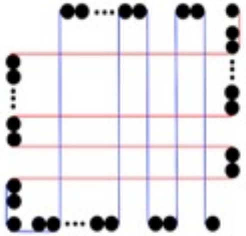
The Detector

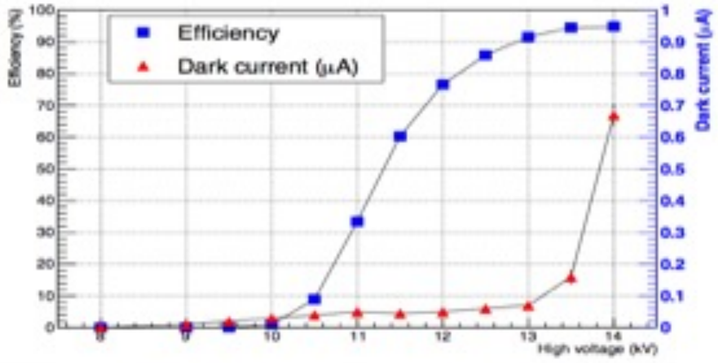
MultiGAP Glass RPC is an excellent candidate.
5-gap of 200 µm each separating glass plates of 250 µm thick can provide a time resolution of around 100 ps

The standard method to build MRPC is based on using fishing line



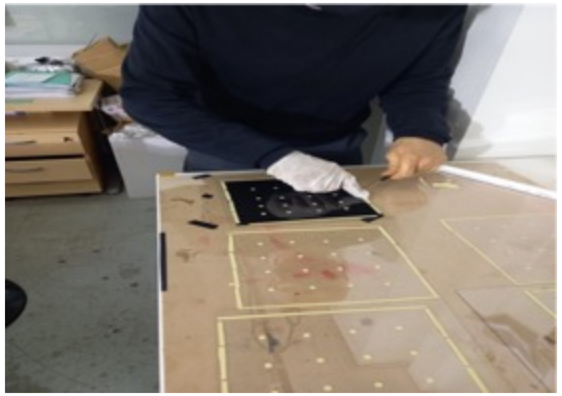


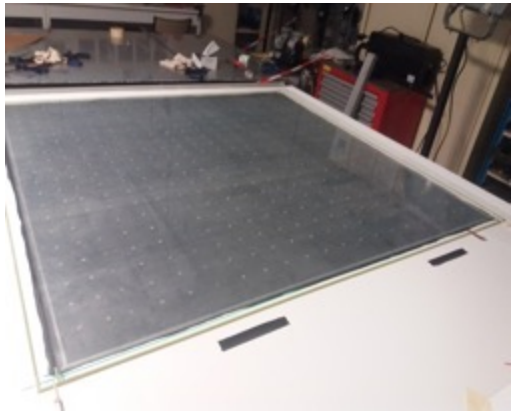




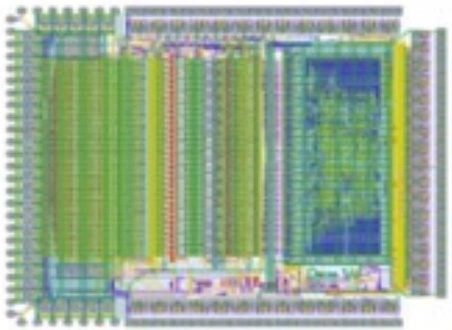
Threshold sets at 114 fC

New and easy way of construction MRPC. Preliminary results show an efficiency > 93% with 5 gaps





Electronics Readout

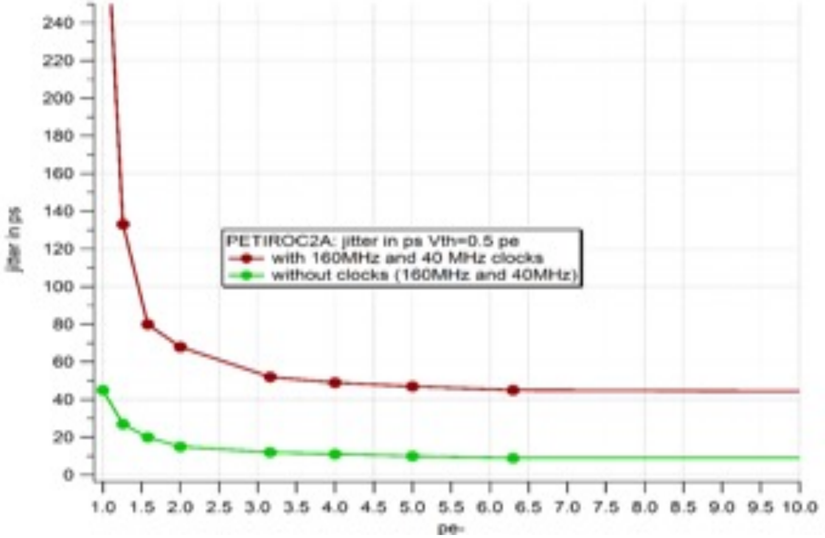


An **ASIC** with a fast preamplifier, precise discriminator and excellent TDC is needed

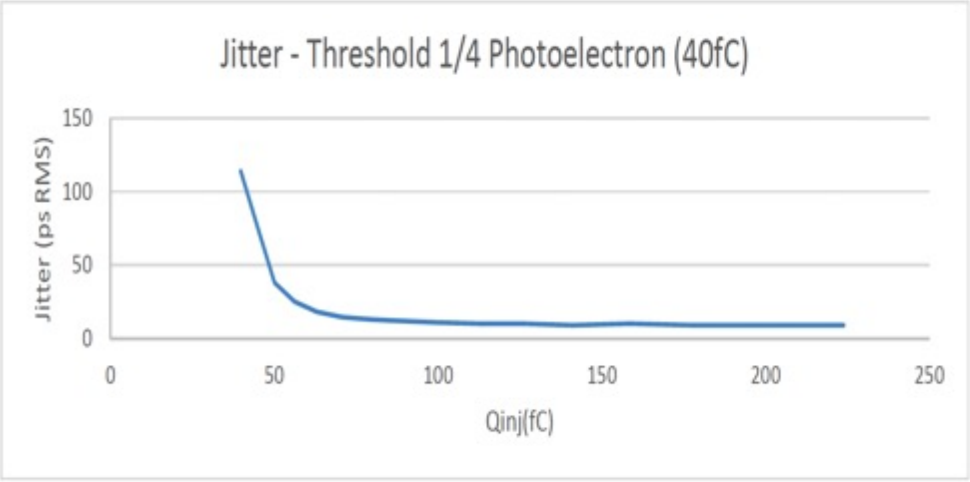
→**PETIROC** 32-channel, high bandwidth preamp (GBWP> 10 GHz), <3 mW/ch, dual time and charge measurement (Q>50 fC)

jitter < 20 ps rms @ Q>0.3 pC

Internal TDC of 50 ps time resolution.



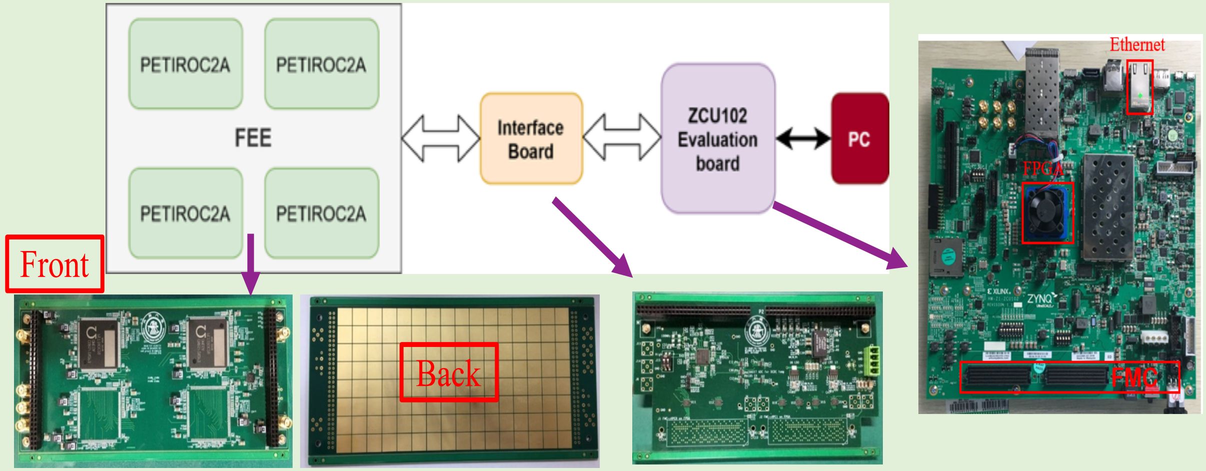
Another ASIC in TSMC 130 nm developed by OMEGA&WEEROC called **LIROC** with a time **jitter < 10 ps** is to be used in the future but it needs to be equipped with an internal TDC before.



Electronics Readout

Small ASU

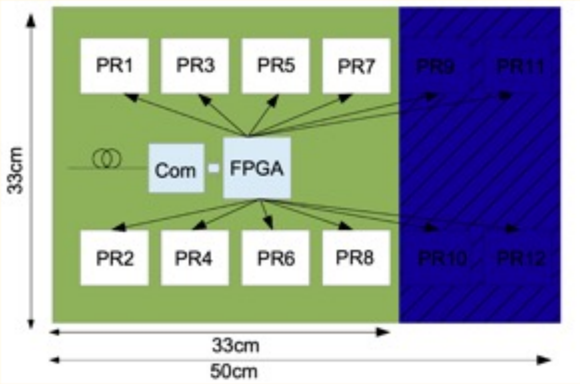
A board with 4 petiroc, 128 pads as well as the whole DAQ system was developed and being tested

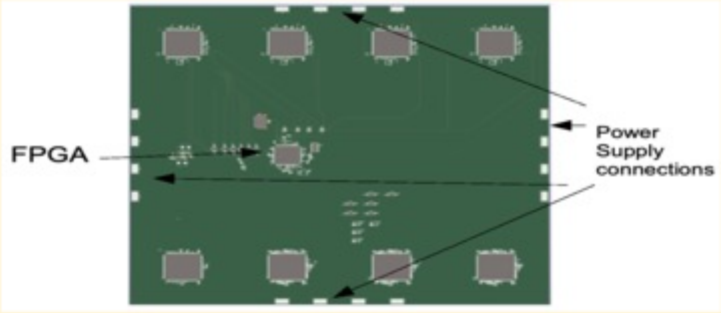


- Front-End Electronics for MRPC readout with high timing resolution
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system(DAQ) based on ZCU102.

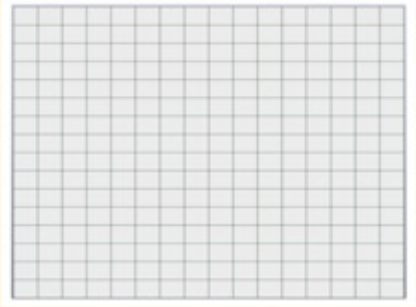
Large ASU

- Board with 8 (could be extended to 12) Petircoc2B ASICs
- Pads 2cm x 2cm, 256 channels
- Local FPGA (Xilinx Spartan-6 TQFP) embedded on board





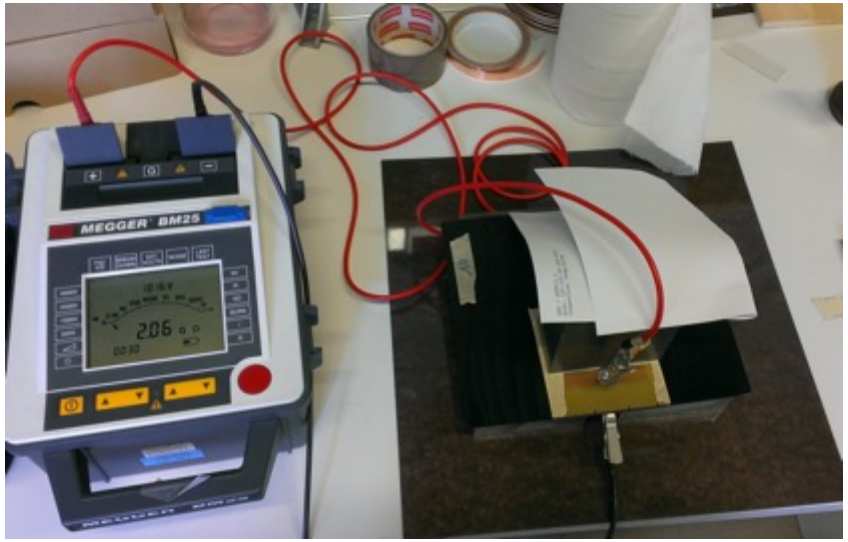
Top view



Bttom view

High-Rate capability

(M)RPC are low-rate capability detectors due to the resistive nature of the electrodes. The capability could be significantly increased by developing low resistivity materials.



Dopped glass (by Tsinghua group) could be a solution

PVdF and **PEEK** are very stable and chemically inert thermoplastic

-New kind of PVdF developed with the help of PolyOne company, doped with CNT → bulk resistivity of $10^{11\text{-}12}$ Ω.cm

-New charged PEEK developed with the help of Krefine company. doped with Black Carbon→ bulk resistivity of $10^{8\text{-}9}$ Ω.cm was achieved.

A few small detectors were made using doped PVdF plates of 2-3 mm thickness.

An excellent efficiency is obtained with cosmic

Plates made with charged PEEK were produced

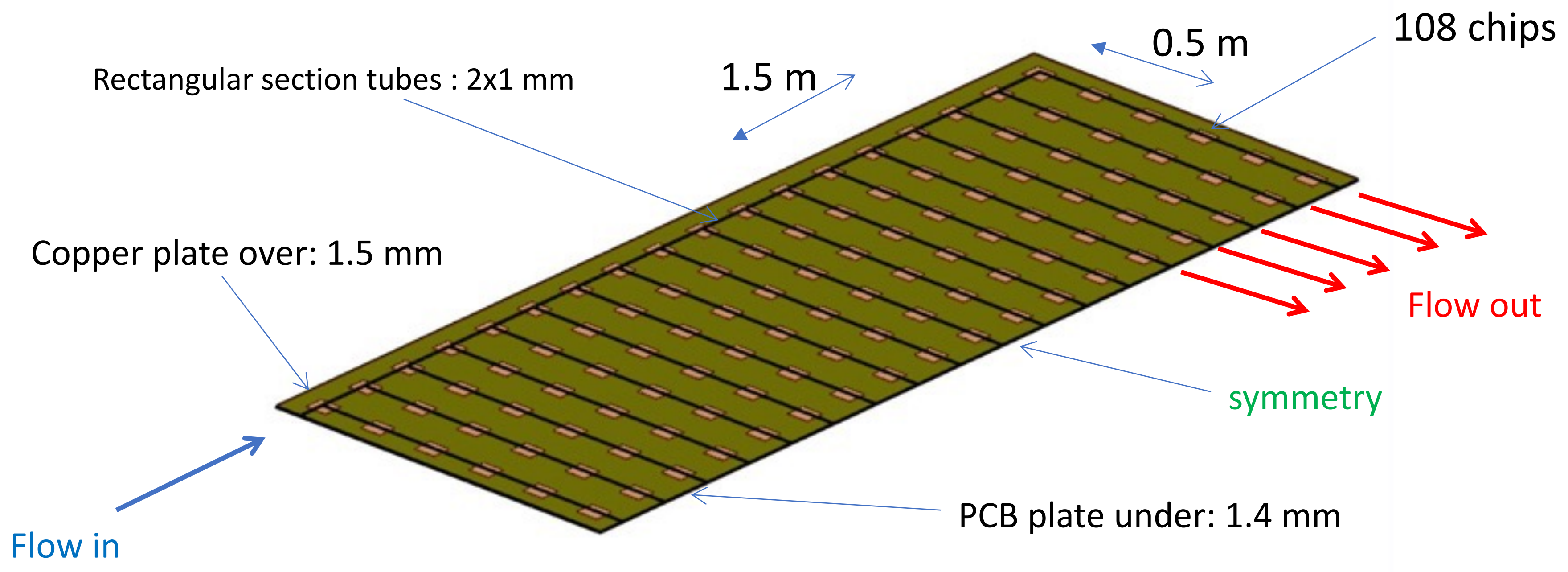
Some homogeneity due to extrusion need to be fixed before to have a final material.

Large SDHCAL module

SDHCAL power consumption and cooling

The duty cycles of CEPC/FCCee are different from that of ILC and no power pulsing is possible.
The power consumption is therefore increased by a factor of 100-200 with respect to ILC and active cooling is needed.
Lyon and Shanghai groups worked on a simple cooling system for SDHCAL based on using water circulating into copper pipes

0.8 mW/chips with power pulsing → 80 mW/chips without power pulsing



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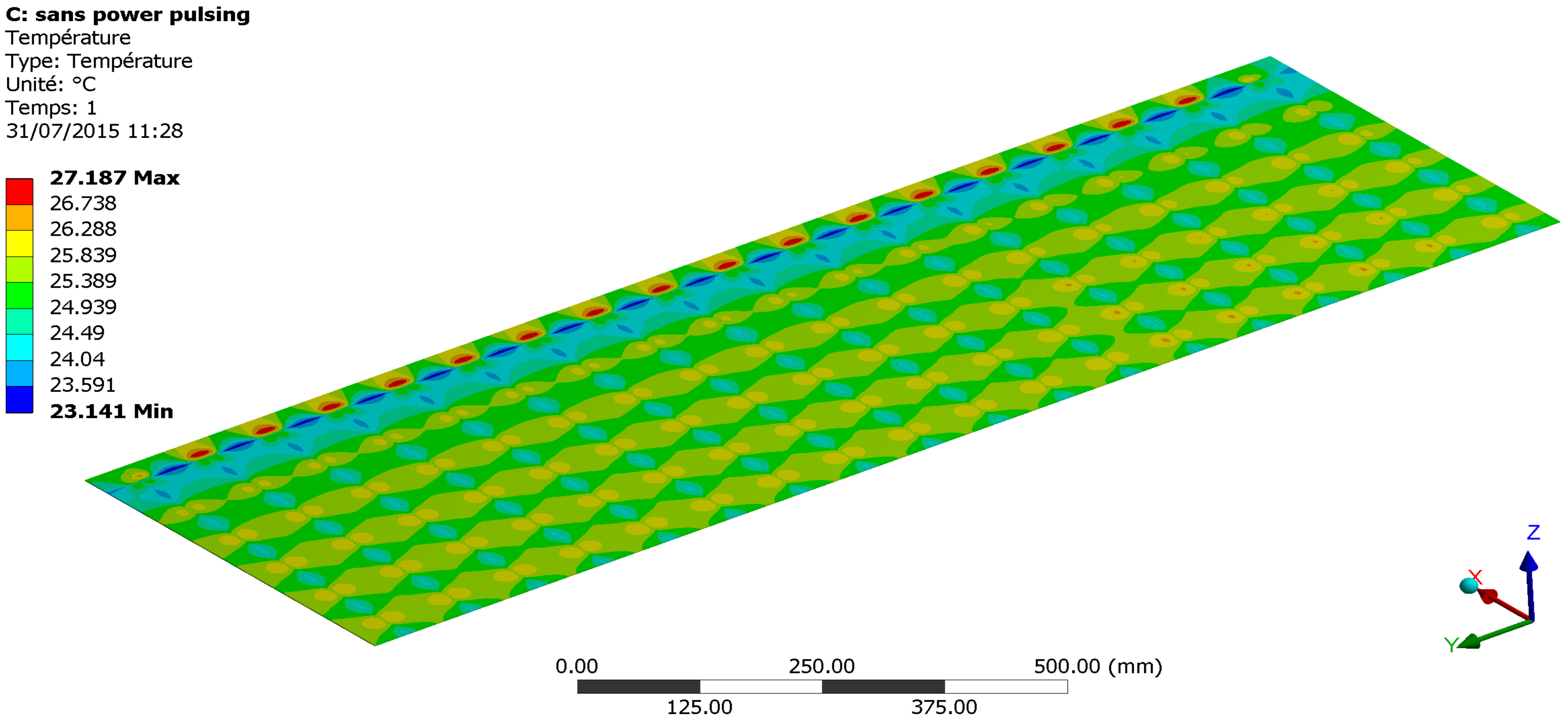


New friendly gases

The CERN gas group has identified friendly gases to replace TFE and SF6 for (M)RPC

TFE→ HFO1234ze
SF6→ Novec 4710 (not good for Bakelite but ok for GRPC and MRPC)

Techniques of recycling the gas mixture is being constantly improved (>90%)
Techniques to recover the different exhaust gases (distillation…etc) are being developed and promising results have been obtained.

Conclusion

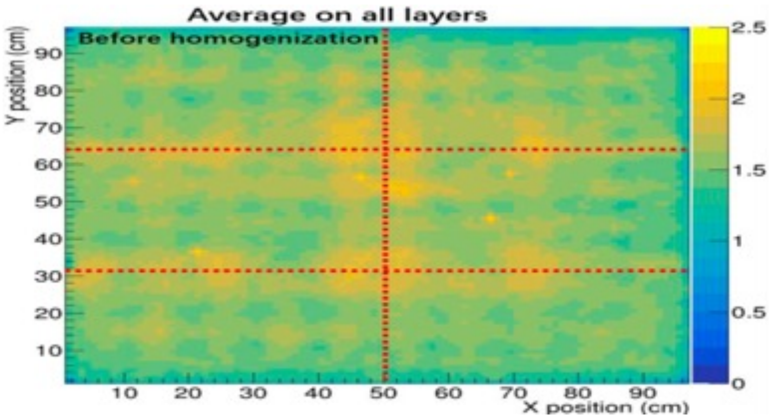
- Several gaseous detectors will be developed to be used as active area in calorimeters
- Efficiency, timing and high rate capabilities are important features to be investigated.
- Synergy between several groups involved in both DRD1 and DRD6 will be a precious tool for the success of the proposed projects

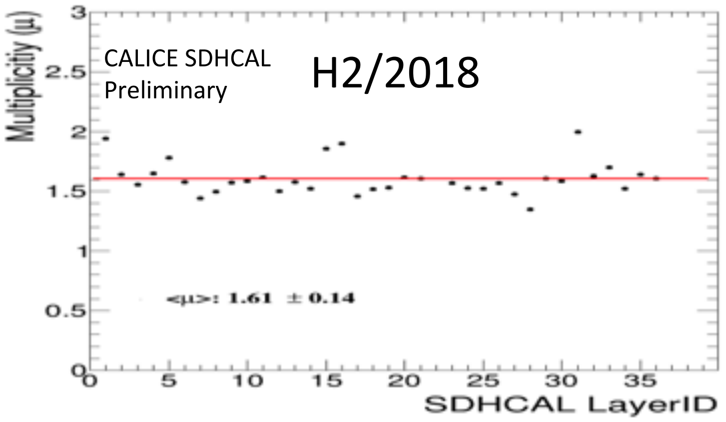
Backup

Further improvements on the energy reconstruction

Detector homogeneity

The homogeneity of the detector response is important to achieve better energy reconstruction





A new calibration method based on varying the thresholds rather than the electronic gain was found to be powerful. Muon runs with different thresholds Thr1: 0.1-0.42 pC, Thr2: 0.4-5, Thr3:4.7-24) and efficiency and multiplicity were measured for each value. The values of the three thresholds of each ASIC were fixed to obtain same multiplicity (first threshold) and the same efficiency for thr2 and thr3.

$$\varepsilon(t;\bar{q},\delta,\epsilon_0) = \varepsilon_0 \cdot \left(1 - \int_0^t P(q;\bar{q},\delta)dq\right)$$

$$P(q;\bar{q},\delta) = \frac{1}{\Gamma\left(\frac{\bar{q}}{\delta}\right)\delta^{\frac{\bar{q}}{\delta}}} q^{\frac{\bar{q}}{\delta}-1} e^{-\frac{q}{\delta}}$$

$$\mu(t;f,p,c) = f \cdot t^p + c$$

Further improvements on the energy reconstruction

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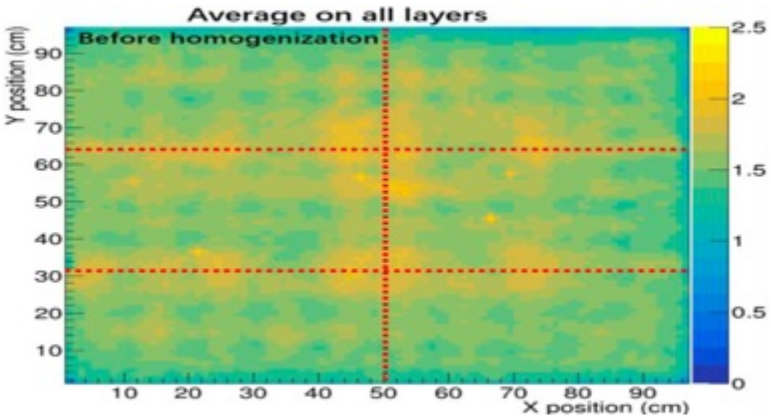

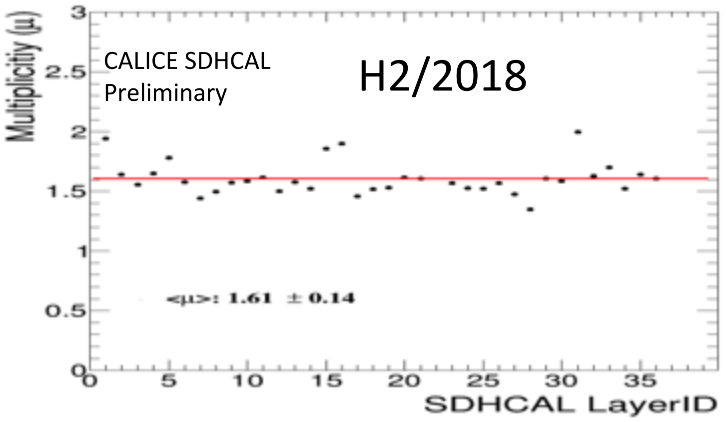

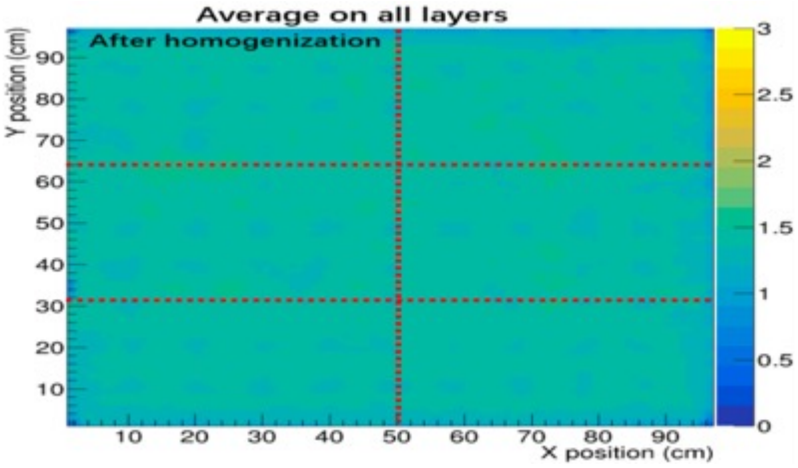

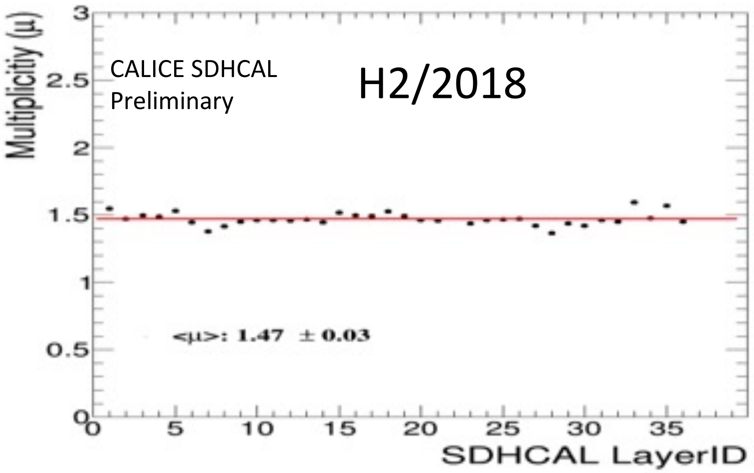

Further improvements on the energy reconstruction

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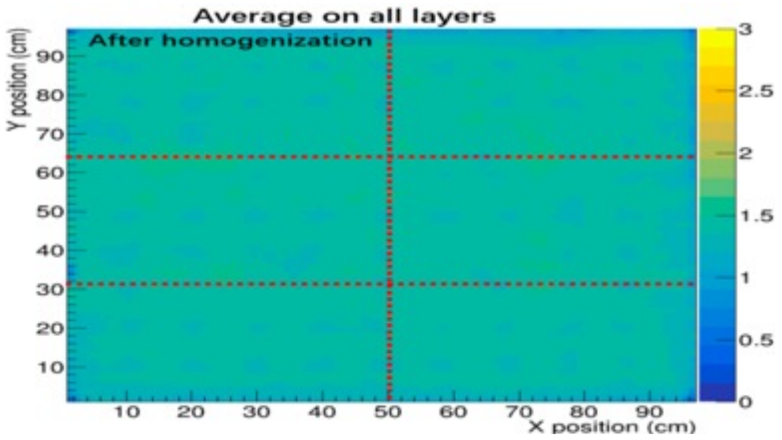

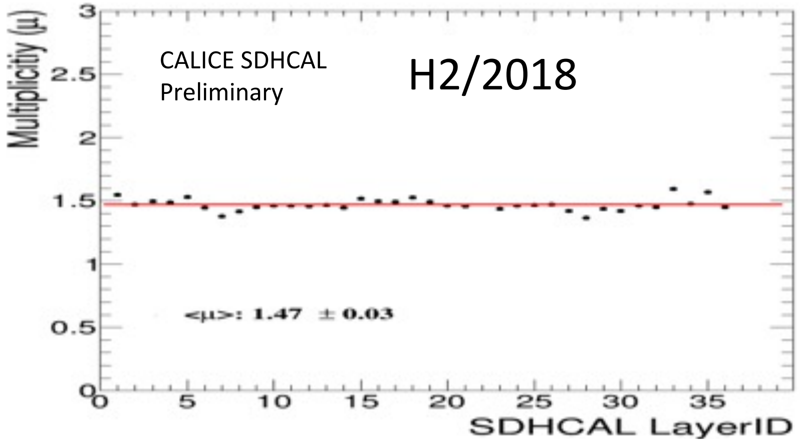

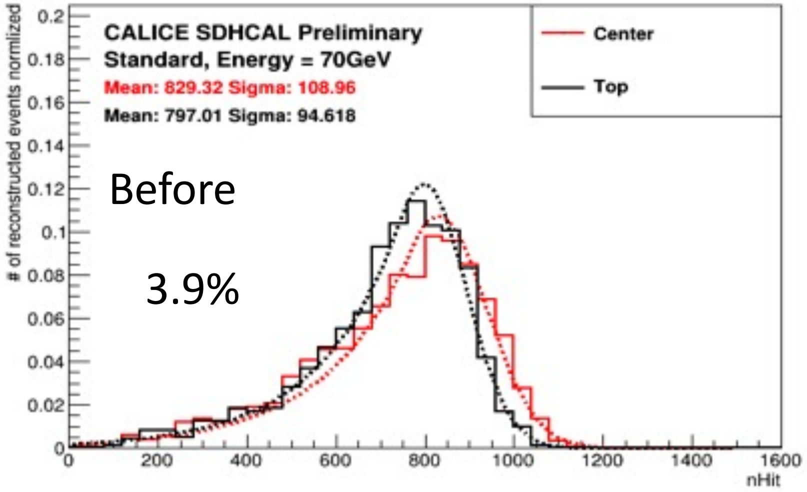

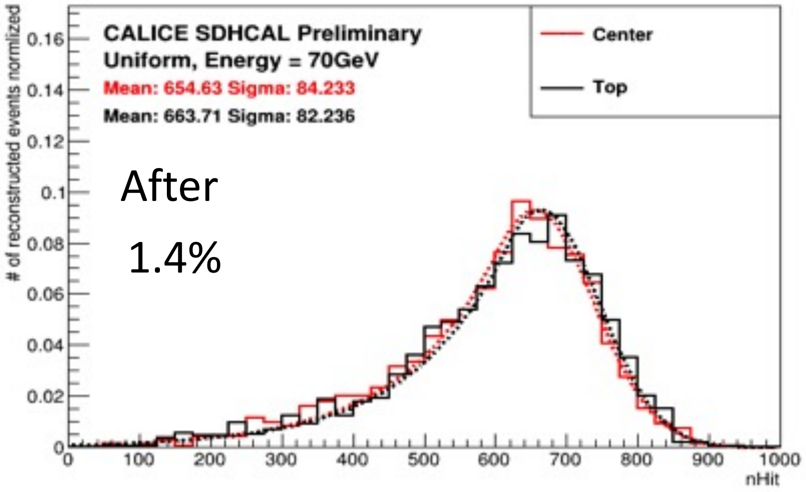

G. Garillot PhD thesis